HIGH DISPERSION SPECTRA OF CP STARS: A PROBLEM IN CLASSIFICATION

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ABSTRACT

High dispersion (2.4 Å mm^{-1}) spectra of chemically peculiar late B and A stars reveal a wealth of information. In this paper we attempt to organize this material by introducing a classification scheme based on the second spectra of the lanthanide rare earths. Four categories are introduced: a) Lanthanide Rich, b) Nd-Sm Anomalous, c) Iron Group-Rich, Rare Earth Moderate, and d) Lanthanide Normal. The variability that is possible in different stellar spectra of Nd II and/or Sm II relative to Ce II, Eu II, and Gd II is a prominent feature of the data. Thus far, the only means of detecting these variations is to use high dispersion spectra. The relationship between our classification and low dispersion spectroscopic and photometric criteria is a problem for the future.

1. INTRODUCTION

For the past several years we have been carrying out a high dispersion survey of chemically peculiar (CP) late B and A stars. Details of this work were summarized by Cowley (1976a) through the time of the Vienna Colloquium: The Physics of Ap Stars.

The observational materials upon which this work is based are primarily 2.4 Å mm^{-1} spectrograms and direct intensity tracings from the Dominion Astrophysical Observatory (DAO). Data for HD 25354 was

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published by Pyper and Hartoog (1975) and Pyper (1976), while that for HD 200311 is taken from the work of Adelman (1974). These authors have been kind enough to provide us with supplementary material in addition to that which appears in their publications.

A list of the stars discussed in this paper is presented in Table I. The Strömgren index (b-y) is given only as a rough indicator of the relative temperature, many of the stars are variable in color as well as spectra. We wish to thank Dr. G. W. Preston for making available an unpublished list of v sin i determinations.

The importance of having spectra with sharp lines cannot be overemphasized. The more rapidly rotating stars in Table I have values of v sin i of only about 20 km/sec, but for these stars the line spectrum is so badly convoluted that one cannot make a direct comparison of the statistical results with those for a star with, say, v sin i $<$ 5 km/sec. The spectra are also distorted by Zeeman splitting and Doppler splitting due to the approach and recession of chemically distinct "patches."

The complexity of the observational data pertaining to CP stars is extreme. Theoreticians are at a disadvantage because many of the facts about these stars are still not widely recognized. Our survey has given us a completely different picture of the CP stars than the one familiar from low dispersion classification because our spectra contain information on elements whose spectra cannot be seen at low dispersion. It is for the future to say whether this new information is of fundamental importance to an understanding of the CP stars.

In this paper we attempt to treat some of the new information by one of the most rudimentary techniques of scientific analysis: classification. A preliminary discussion of the classification was given by Cowley, Aikman, and Fisher (1977). It is based primarily on the relative strengths of the second spectra of the lanthanides. Some consideration is given to the fact that the strengths of these lines are expected to decrease markedly in the hotter stars as the dominant ion becomes the doubly ionized one.

2. THE CLASSIFICATION

A listing of the stars according to the categories into which they have been classified is presented in Table II. A few of the spectrum variables are listed twice, the different spectrograms being distinguished by an "a" or "b" appended to the star name. For example, HR 465(a) refers to the well known rare earth (RE) maximum spectrum studied by Dr. W. P. Bidelman. HR 465(b) refers to a 1974 spectrogram obtained at the DAO, which is rather typical of sharp-lined Ap spectra.

TABLE I

STARS CLASSIFIED

Star	Sp Pec	b-y	v sin i	Ref
10 Aql	F0p Sr Eu	+.148	≤ 6	1,2,11
32 Aqr	A5m	+.124	<10	1,12
53 Cam	A2p Sr Cr Eu	+.057	<20	1,8,12
49 Cnc	A1p Eu Cr	-.080	19	1,8,11
β CrB	A8 Sr Cr Eu	+.124	≤ 3	4,2,11
α^2CVn	A0p Si Eu Hg	-.060	24	1,8,12
73 Dra	A0p Sr Cr Eu	+.007	8	1,8,12
γ Equ	A7 Sr Cr Eu	+.135	≤ 3	2,4,11
52 Her	A2p Sr Cr Eu	+.037	24	1,8,12
45 Leo	A0p Si(Cr)	-.037	13	1,8,12
33 Lib	A9 Sr Cr Eu	+.209	10	2,4,12
ζ^1 Lyr	A4m	+.085	28	1,3,11
41 Tau	B9p Si	-.069	21	1,8,11
63 Tau	A1m	+.180	<10	1,12
τ Uma	A4m	+.190	<10	5,10,11
78 Vir	A1p Cr Sr Eu	-.008	10	1,2,12
HR 465	B9p Cr Eu(Sr)	-.040	≤ 6	1,8,12
HR 1094	B9p		25	1,8
HR 4751	A2m	+.120	<12	1,12,15
HR 4816	A0p Sr Cr Eu	+.027	≤ 6	1,2,14
HR 4854	A0p Sr Cr Eu	-.063	10	1,2,14
HR 6560	A7m or Fm	+.373	≤ 7	5,10,12
HR 6958	A0p Si Cr	-.052	9	1,8,12
HR 7575	Ap (Cr Eu)	+.045	≤ 4	1,8,14
HR 8216	A6p Cr(Eu)	+.055	≤ 6	1,2,12
HD 2453	A0 Sr Cr Eu	-.005	≤ 6	2,4,12
HD 8441	B8 Sr Cr Eu	+.016	≤ 6	2,4,11
HD 25354	A2 Sr Cr Eu	-.043	18	4,8,11
HD 42616	B8 Cr Sr Eu	+.049	23	4,8,11
HD 51418	A0p(Eu Sr Cr)		≤20	6,8
HD 71866	B9 Sr Cr Eu	+.014	17	4,8,12
HD 101065	Lanthanide	+.452	<10	7,10,13
HD 200311	Si Sr Cr	-.071	≤10	8,9,11
HD 216533	B9 Sr Cr	+.014	7	2,4,12
HD 221568	A0 Sr Cr Eu		≤ 6	4,8

(1) Cowley et al. (1969); (2) Adelman (1973); (3) Abt and Hudson (1971); (4) Osawa (1965); (5) A. Cowley (1976); (6) Hardorp (1975); (7) Cowley et al. (1977); (8) Preston (1978); (9) Adelman (1974); (10) Estimate, this paper; (11) Philip, Miller, and Relyea (1976); (12) Lindeman and Hauck (1973); (13) Heck et al. (1976); (14) Warren (1973); (15) Smith (1971).

TABLE II

THE CLASSIFICATION

Star	CL	N	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er
HR 465(a)	A	4293	-	-	5.9	0	10.0	13.0	+	11.8	4.4	10.7	4.6^{III}	6.2
HR 6958	A	1437	-	-	12.8	0	6.5	+	4.7	+	0	5.6	-	-
HD 25354(a)	A	1396	-	-	+	0	9.7	4.6	5.8	0	-	+	-	-
HD 25354(b)	A	1353	-	-	6.0	4.3	6.7	5.2	6.3	+	-	+	-	-
HD 51418	A	1444	-	0	-	0	5.0	+	6.0	0	0	+	4.4	-
HD 101065	A	2821	4.6	8.0	10.9	5.9	9.9	11.8	4.1	6.7	0	5.9	5.2	6.8
HD 192913	A	1149	-	-	0	0	4.9	0	5.7	0	0	4.1	6.6^{III}	4.8
HD 200311	A	1119	-	0	13.5	+	-	-	0	0	-	-	-	-
HD 221568(a)	A	3332	0	-	7.7	-	7.1	8.0	+	7.0	-	3.9	0	+
HD 221568(b)	A	2792	3.6	-	10.8	-	5.6	0	+	6.9	-	0	-	-
10 Aql	B	2872	+	+	8.2	-	+	8.2	+	7.1	-	+	-	-
β CrB	B	2610	+	4.0	8.4	-	-	-	0	5.2	-	-	-	-
52 Her	B	1124	-	0	4.2	-	-	-	+	+	-	-	-	-
HR 7575	B	2485	-	5.4	7.5	-	-	0	+	9.1	0	-	-	-
HD 71866	B	1353	0	5.0	7.1	-	0	0	4.3	+	0	-	-	-
53 Cam	C_1	1099	-	8.4	6.1	-	-	-	-	-	-	-	0	0
49 Cnc	C_1	954	-	0	+	5.7	-	0	0	-	-	-	-	-
α2 CVn	C_1	1115	-	-	7.3	0	0	-	-	-	-	-	-	-
45 Leo	C_1	1041	-	0	7.6	+	-	-	-	-	-	-	-	-
41 Tau	C_1	367	-	-	4.5	-	+III	-	-	-	-	-	-	-
78 Vir	C_1	1553	-	0	4.0	-	-	-	0	-	-	-	-	-
HR 465(b)	C_1	2039	-	0	11.9	-	4.4	-	-	+	-	-	-	-
HR 4816	C_1	1969	-	+	+	-	-	-	-	-	-	-	-	-
HR 4854	C_1	1798	-	-	4.9	-	0	-	0	-	-	-	-	-
HD 2453	C_1	2582	4.6	-	7.2	-	0	-	+	-	-	-	-	-
73 Dra	C_2	1844	+	-	-	-	-	-	+	-	-	-	-	-
HR 8216	C_2	1749	0	-	-	-	-	-	-	-	-	-	-	-
HD 8441	C_2	1925	-	0	-	-	-	-	-	5.6	-	-	-	-
HD 42616	C_2	755	-	-	-	-	-	-	-	-	-	-	-	-
HD 216533	C_2	1917	-	-	-	-	-	-	+	-	-	-	-	-
32 Aqr	D	1553	4.9	8.7	10.2	-	9.0	5.3	4.3	5.2	-	4.5	-	-
γ Equ	D	2023	6.7	7.4	9.1	0	9.5	4.3	+	8.1	-	6.1	-	-
33 Lib	D	2008	3.5	3.8	7.3	0	4.2	5.6	0	7.5	-	3.9	-	+
63 Tau	D	1271	5.3	6.2	10.3	+	8.4	+	6.0	+	-	0	-	-
τUMa	D	1679	5.2	7.0	8.7	+	8.3	6.4	4.0	6.0	-	5.0	-	-
ζ^1 Lyr	D	577	5.6	3.6	4.3	-	0	4.4	-	-	-	-	-	+
HR 4751	D	490	-	0	+	-	0	0	-	-	-	-	-	-

The number of lines N measured in the spectrum is given in Table II for yttrium and the lanthanides, an indication of the confidence level at which the second spectrum can be identified. The format follows Cowley (1976b), who gives epochs of the spectrograms. A few additional plate epochs are in Cowley, Aikman and Fisher (1977). A "-" means the spectrum cannot be identified at the 95% or higher confidence level; "o" indicates an identification at the 95-99% confidence level. The numerical values are the parameter S (cf. Hartoog et al. 1973), which roughly speaking, measures the confidence level of the identification in standard deviations. S is often a useful indicator of the relative strength of an ionic spectrum. A numerical value for S is only entered if $S > 4.0$. Between the 99% confidence level and $S = 4.0$, we enter a "+".

The classification scheme closely follows Cowley, Aikman, and Fisher (1977), with one significant change. Category C, which was previously called "chrominum-manganese, moderate RE stars," has now been divided into C_1 and C_2, depending on the strength of the Ce II lines. In addition, it has seemed more appropriate to describe these spectra as iron group (Sc-Ni) strong, rather than singling out chromium and manganese, since Ti II, Fe I and Fe II are often of unusual strength in these stars. HR 1094 has extraordinarily strong Co II lines. A general discussion of the different categories follows.

2.1 Category A: Lanthanide-Rich Stars

HR 465(a) and HD 221568 (Osawa's star) have the sharpest lines and are therefore the best-studied stars in this group. RE abundance excesses in these stars, as determined from formal analyses with plane parallel "classical" atmospheres range up to 10^5 for Nd and Sm. Nd II and Sm II show pronounced variability. They are the strongest when Cr I and II are weakest.

The spectra of stars in Category A are of vastly different appearance from those in the other categories. The spectra of the stars within the category are by no means identical, but it is clear that they share the property that the spectra of the rare earth elements (REE) are enormously enhanced relative to the iron group. It is often difficult to identify a spectral region by an intercomparison of tracings (which have the same dispersion!) of, say, HD 221568 (Category A) and γ Equ (Category D). The differences between γ Equ and, e.g., β CrB (Category B) are very real, but nowhere near as extreme.

All of the stars except for HD 101065 (Przybylski's star) are at the higher temperature range of stars showing lines due to rare earth elements (REE). If we make a comparison of the strengths of, say, the Ce II lines, which are well-represented in all four categories, the equivalent widths are not markedly different from those in stars with similar values of S. The huge abundance excess for the lanthanide-rich stars derive from the fact that in the model atmospheres, the singly ionized state is not the dominant stage of ionization.

Przybylski's star is an exception. It is surely cool enough that the singly ionized state is dominant, and the lines due to RE spectra are huge! The well-established weakness of the iron group spectra in HD 101065 is suggestive of the out-of-phase variations of RE spectra with Cr II (and Mn II) in HR 465 and Osawa's star as well as many other Ap stars.

HR 465(a), HD 221568, and HD 101065 have outstanding lines of Nd II and Sm II relative to Ce II. The variability of Nd II and/or Sm II, both in and among stars, is fundamental to the present classification.

Stars in Category A may be distinguished from those in the other categories by (a) the strength of Nd II and Sm II relative to Ce II, (b) the weakness of La II and Y II, and (c) the presence of Dy II and/or Ho II or Ho III. Not all stars have all three characteristics, but there is only one star for which membership is problematical, HD 200311. This star might well be put into Category C_1. We call it lanthanide rich, primarily because its high T_{eff} implies that the REE must be primarily doubly ionized.

2.2 Category B: Stars With a Nd-Sm Anomaly.

The weakness of Nd II and Sm II in stars of this category relative to La II and Ce II is striking. β CrB and HR 7575 are the best examples of stars in this group because their spectra have the sharpest lines. The lines in 10 Aql are also extremely sharp, but this star has only a partial claim to membership in Category B, because Sm II is quite strong, while only Nd II is weak or absent. It is entirely possible that the "weakness" of Nd II and Sm II in 52 Her and HD 71866 is due to the considerable rotational broadening of the lines in these stars. We can only draw attention to the fact that Ce II and Gd II had sufficiently strong lines that a statistically significant number of blends were dominated by their spectra, while Nd II and Sm II, if present at all, were lost in the noise.

Although Ce II, Eu II, and Gd II are very strong in these objects, Dy II is weaker. We find no evidence for Ho II or any heavier lanthanide spectra in stars of this category.

2.3 Category C: Iron Group Rich, Moderate RE Stars

The C_1 subgroup (CE II strong) is the most typical of the CP stars of the magnetic sequence. Lanthanide abundance in some of these stars could be similar to those of Category D, but because of the weakness of the spectra due to double ionization, only Ce II dominates. On the average, the stars in Categories C_1 and C_2 are hotter than those in Category D.

Tracings of stars in C_1 resemble one another rather closely. although there are definite differences to be seen among them. Usually these differences are for elements whose ions do not have rich spectra or have only a few strong lines. Most of these stars have remarkably strong spectra of iron group elements. High dispersion spectroscopists have been aware for some time of an antipathetic relation between the spectra of chromium and the REE. HR 465 is an illustrative example. At RE maximum, the Cr I and II lines are very weak. In HR 465 Mn II varies in phase with Cr I and II. In some of the C_1 stars the strength of Mn II is quite sufficient to entitle them to be called manganese stars.

Our inclusion of the well-studied α2CVn in Category C_1 rather than A is at present purely formal and is based on the wavelength statistics alone. Pyper (1969) discussed the different systems of radial velocities that exist for this star, which would certainly decrease the effectiveness of the analysis for wavelength coincidences. Note, however, that Ce II was identified, and at a very high confidence level, as were Si II ($S = 4$), Ti II ($S = 11.5$), Cr II ($S = 9.3$), Fe I ($S = 5.9$), and Fe II ($S = 11.5$). Perhaps it is unfortunate that this star has been regarded as a prototype Ap star, since rotational broadening and line doubling make it much more difficult to study this object than its congeners with sharper-lined spectra.

The stars in the C_2 subgroup constitute a very "mixed bag." Their common denominator is the strength of iron-group spectra. The REE in each star deserve separate description. At the phases of our data (cf. Cowley et al. 1977) there is little evidence for more than one RE, but the Eu II lines are often remarkably strong. HR 8216 has the weakest lines of REE of any Ap star that we have studied. The lines in the spectrum of HR 8216 are quite sharp, so that weak lines can be detected. It is not at all impossible that some REE may actually be underabundant in the photosphere of HR 8216! HD 8441 surely has Gd II, but lacks evidence for any other RE spectrum. The rotational velocity of HD 42616 makes it impossible to say more than that, if spectra of REE are present, they must be weaker than in the atmospheres of stars with comparable v sin i's which do exhibit these elements (c f. 52 Her, HD 71866). Eu II is present in the spectrum of HD 216533, but its strength is not outstanding, while 73 Dra has strong Eu II lines.

2.4 Category D: Rare Earth Normal

This is a temporary designation, since it is probable that departures from "normality" will eventually be found among the RE abundance patterns in some of these stars.

"Normality" as used here means a similar abundance pattern to that found in chondrites (cf. Haskin et al. 1966), for which the relative abundances of the REE are remarkably uniform. The abundances in Table III are from Haskin and Paster (1978), normalized to unity for cerium. Data for yttrium is from Cameron (1973) and Moore (1970). In addition, we list the first four ionization energies, as given by Martin et al. (1974), which are indicative of the spectroscopic uniformity of the lanthanide REE.

It is seen that cerium is the dominant lanthanide in abundance among the chondrites. We find it difficult to believe that it is a mere coincidence that Ce II is the dominant lanthanide spectrum among those securely identified of the stars listed in Table II. After cerium, the abundances generally decrease with atomic number Z, preserving the odd-even abundance alternation that arises from the properties of atomic nuclei.

The stars in Category D are called "Rare Earth Normal" primarily on the strength of Hundt's (1972) fine study of 63 Tau, which showed no credible departure of the RE abundances from the chondritic pattern. For the present, there is no basis in the data that we have assembled to believe that any of the other stars in Category D have a significantly different RE abundance from 63 Tau.

Two of the stars are in the magnetic CP star sequence: γ Equ and 33 Lib. All five are among the coolest CP stars. 32 Aqr is probably the hottest of the five, and τ UMa the coolest.

Lines of the REE are generally strong in the non-magnetic stars. For the present, we assume this reflects abundance differences. It appears that the overabundance factors for the REE are somewhat greater among the Am stars than among the Ap stars, a result which conflicts with traditional "lore," but which, at least for this group of CP stars, is difficult to escape.

We have no evidence for a Nd-Sm anomaly among Am stars, but this could be nothing more than a vagary of our small data sample.

TABLE III

"COSMIC" ABUNDANCES AND IONIZATION POTENTIALS OF YTTRIUM AND THE LANTHANIDES

EL	Abundance	χ_{I}	χ_{II}	χ_{III}	χ_{IV}
Y	4.1	6.4	12.2	20.5	61.8
La	0.37	5.6	11.1	19.2	50.0
Ce	1.00	5.5	10.8	20.2	36.8
Pr	0.13	5.4	10.6	21.6	39.0
Nd	0.68	5.5	10.7	22.1	40.4
Sm	0.21	5.6	11.1	23.4	41.4
Eu	0.08	5.7	11.2	24.9	42.6
Gd	0.28	6.1	12.1	20.6	44.0
Tb	0.05	5.9	11.5	21.9	39.8
Dy	0.36	5.9	11.7	22.8	41.5
Ho	0.08	6.0	11.8	22.8	42.5
Er	0.23	6.1	11.9	22.7	42.6
Tm	0.03	6.2	12.0	23.7	42.7
Yb	0.23	6.3	12.2	25.0	43.7
Lu	0.04	5.4	13.9	21.0	45.2

3. DISCUSSION

Some 35 spectra have been classified into 5 categories (counting both C_1 and C_2), and although there are a few stars that are difficult to classify, the ambiguous cases are no more troublesome than similar situations that arise in traditional, low dispersion classification. Our scheme is not intended to be a definitive one, or to replace any now extant. The significant point of our endeavors is that new information has come to light as a result of our CP star survey, and that this information can be organized by the technique of classification. There is an alternative to simply giving a number -- such as an abundance for each lanthanide.

If we were to introduce criteria other than RE spectra, our groups could easily be split into individuals. It is important to know whether these individuals are unique or whether their distinctiveness is just a manifestation of our present very small data sample. An attack on this problem is an important one for the future of spectral classification. What is required is a larger sample of stars with sharp-lined spectra.

It would be valuable to have a survey of the HD stars, say between B8 and F0, fainter than the limit of the Bright Star Catalogue, which would pick out stars with v sin i < 20 km/sec. According to the spectroscopist's rule-of-the-thumb, this would require dispersions of 20 Å mm^{-1} or "higher." Stars in Osawa's (1965) catalogue have already been surveyed by Preston (1978) and need not be repeated.

Can photometric criteria be devised which could discriminate among the categories of stars presented here? This also is a problem for the future.

Finally, we remark that classification is only a first step in a scientific analysis. We hope that the patterns of the REE in CP stars will help to clarify the nature of these objects.

This entire study has been carried out in close collaboration with G. C. L. Aikman of the DAO, whose help is gratefully acknowledged. It is also a pleasure to acknowledge advice and/or conversations with S. J. Adelman, W. P. Bidelman, A. P. Cowley, B. Hauck, and M. R. Hartoog. My thanks are once again due to Director van den Bergh and the staff of the DAO. This research was supported by the National Science Foundation.

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DISCUSSION

Gratton: The problem is whether the anomalous behavior of these elements in A stars is also observed in other spectral types. In K giants we have observed many lines of the rare earths (indeed they are the richest spectra after the iron-group ones), but so far we have not detected any difference between different stars (at 3 Å mm^{-1} dispersion).

Cowley: This is my experience with the later spectral types too. It is different from the A stars. I have looked at descriptions of the spectra of long period variables in an attempt to find evidence of severe fractionations among the rare earths. One can find such evidence, but the interpretation of the line strengths is complicated by molecular formation.

Gerbaldi: It is remarkable that in your classification you have in the same classes both Ap and Am stars. It is suggested that the Ap and Am phenomena are due to a diffusion process which can take place in a quiet atmosphere. Do you intend to extend your analysis in that direction, by looking for any correlation between diffusion hypothesis predictions and the results of your classifications?

Cowley: I hope that we can persuade theoreticians to make calculations relevant to these rare-earth fractionations. Thus far, most calculations have lumped rare earths together.

Gerbaldi: As regards the problem of defining photometric criteria to represent your classifications, there are the following constraints:

(a) The lines involved are faint (∿100 mÅ equivalent width, I imagine)

(b) These lines are not, I suppose, grouped together by chance, but spread all over the spectrum, so that it seems rather difficult to define photometric bands, which must have at least a few angstroms width.

Thus it seems that an appropriate system for such photometric observations will be one involving the use of a reticon or silicon device. To be useful for such a purpose, these devices must be used in conjunction with a low resolution (∿3Å) spectrograph. It will be necessary to look carefully at high resolution spectra to see in which windows lines of other elements are present, besides the interesting lines involved in your criteria. If spectra are digitized it is rather easy to perform numerical experiments for any photometric system we can imagine.

Cowley: I agree that it would be very difficult to measure the strengths of rare earth lines with standard photometric methods. It might be useful to try to achieve a more limited objective. For example, the iron peak elements are normal, or only marginally enhanced in our Category A, while they are very strong in C_1 and C_2. Stars in all three categories have been called Cr-Eu or Sr-Cr-Eu. Perhaps we could make a discrimination on the basis of the iron peak spectra, which are far more abundant and have stronger absorption features, certainly in the UV.

Jaschek: I am very impressed by your work which is the first determined effort in the last few years to introduce more order into this very complicated group of stars.

My questions are two: (a) what is the lower limit of high dispersion material with which to do such kinds of studies? (b) what about spectrum variability?

Cowley: Some very peculiar stars, such as HD 51418, with v sin i between 10-20 km sec^{-1} could be studied to good advantage with dispersions of 10 Å mm^{-1} and perhaps somewhat lower. However, there is no doubt that the intrinsically low-resolution of the spectra of these stars severely limits the amount of information that we can gather about them. On the second point, the classification as presented here depends on the epoch in which the particular plate was taken. For example, the rare-earth maximum (∿1960) spectrum of HR 465 has been classified into Category A, while in 1974, the spectrum has been put into Category C.

Floquet: Did you look for any correlation between your groups and the strength of the magnetic field of these stars?

Cowley: We did look, although perhaps not as carefully as one would like. It would be useful to do this by the method of multivariate analysis. As far as I know, there is a curious lack of correlation between the magnetic field strength and the degree of chemical peculiarity, beyond the general, loose connection between "some" peculiarity and the presence of magnetic field strength.

Fehrenbach: CI Cyg, whose brightness increased in 1975 from 12^m to $8^m_.5$, shows a A81a spectrum which becomes G5(?)Ia and shows then very strong rare earth lines which appear within one day. At that time the atmosphere of the star is imploding.

Cowley: I would be very interested to know whether the rare earth lines that you saw were due to CeII or NdII, etc. As a general comment, one expects the rare earth lines to strengthen when one compares G stars with A stars having similar abundances.

It remains to be seen whether one can account for the rapid appearance of these lines in terms of excitation and ionization alone.

Wing: If one were able to set up a photometric system that succeeded in classifying the sharp-lined stars into your five categories, would you expect that it would correctly classify the rotators as well? This would certainly help in determining the frequency of occurrence of stars in each category.

Cowley: I think that the answer to this is that we really do not know. It would be extremely interesting to find out. As far as the lanthanides are concerned, I know of no evidence for a correlation of abundance excesses with rotation, but this statement has meaning only within the restricted range, $v \sin i \leq 30$ km/sec, where we have been able to make secure identifications of lanthanide spectra.

Nesu: Did you look for any evidence of duplicity in your spectra?

Cowley: Yes we did. We have a provision to scan in radial velocity which enables us to look for a second spectrum. We have studied some known spectroscopic binaries that are double lined. But in general, I think it unlikely that the complexity of our abundance patterns is due to binarity because there are no systematic differences in the wavelengths of the spectra we identify, except for small shifts which can be explained in terms of the approach and recession of chemically peculiar patches.